Measured Leakage Pressures from a Test Structure Through Covered and Uncovered Vent Areas

by

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1.0 Introduction

Explosives processing and testing bays are often constructed with a lightweight vent panel to allow quasistatic blast pressures to vent from the bay in the event of an accidental explosion. The use of a vent panel limits the damage caused to the bay during an explosion but it allows shock waves to propagate outside the bay and load nearby bays and/or inhabited areas. These blast pressures, known as leakage pressures, have been measured in a limited number of previous experimental programs. Most of these test series have concentrated on leakage pressures through uncovered vent openings from explosions occurring at the geometric center of the bay. During a recent test program conducted at Southwest Research Institute, leakage pressures were measured through both covered and uncovered vent areas from explosions occurring at various positions within the test structure. The test series, which was sponsored by the U.S. Department of Energy, was conducted to investigate the breakup and fragmentation of wall panels subjected to a large blast loads. However, the geometry of the test structure used during many of the tests was such that leakage pressures could be measured concurrently with wall breakup. This paper describes the leakage pressure measurements and compares the measured leakage pressures to those measured in similar testing programs from structures of different geometry with different charge placement and venting characteristics. The effect of a vent panel on the leakage pressures is also discussed.

2.0 Background

There have been a limited number of previous test programs where leakage blast pressures were measured. The most extensive program investigating leakage pressures was conducted at the Naval Civil Engineering Laboratory (NCEL) in 1975[1]. In these scale model tests, leakage pressures

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were measured outside bays with two basic geometries (rectangular and cubic), bays with and without roofs, and bays with loading densities (the ratio of charge weight to room volume) varying from 0.009 lb/ft³ to 0.25 lb/ft³. Cylindrical charges of Composition B explosive with a 1:1 length to diameter ratio were used in the tests. Leakage pressures were measured through three types of uncovered openings; 1) an open side of a bay, 2) an open side and open roof, and 3) an opening within the roof (such as a short vent stack). Pressure histories were measured at a number of scaled distances along lines away from the front (in the direction of the open side), out the side, and out the back of the bays. Pressures were measured out the sides of the bays with partial openings in the roof. Based on approximately 100 measured blast pressure histories made during six tests, design curves (curve-fits to the data) were developed which predict leakage peak side-on pressure and total positive phase impulse outside bays through each of the three types of openings which were investigated. These design curves are included in the updated version of TM5-1300[2].

In 1967 three full scale tests were conducted in China Lake, California where leakage pressures were measured from explosive charges ranging from 1000 lbs to 5000 lbs of TNT through an open side and open roof of 40 ft x 20 ft x 10 ft bays. Information on these tests is summarized in Reference 1. The measured peak pressures were approximately 20% less, and the positive phase impulses were approximately 20% to 40% less, than those measured in comparable scaled tests in Reference 1 at NCEL. Possible reasons for this discrepancy given in Reference 1 include differences in charge shape and the range of loading densities and inaccuracies in scaling.

In 1986 the Terminal Effects Research and Analysis Group of the New Mexico Institute of Mining and Technology performed a comprehensive series of tests for NCEL[3] where leakage pressures were measured outside a missile test cell. Scaled tests (1:2.6 scale) were conducted at loading densities ranging from 0.005 lb/ft³ to 0.045 lb/ft³ where leakage occurred through a wall opening with a scaled vent area (the ratio of the vent area to the room volume to the 2/3 power) of 0.34. This scaled vent area is considerably less than that corresponding to a whole side of the test cell. Tests were conducted with no covering over the vent area and with panels over the vent area which had charge weight scaled areal densities ranging from 9 to 41 psf/lb¹ᐟ³. These areal densities correspond to panels which are much heavier than a typical light metal wall with insulation. In some cases the panels were recessed relative to the outer face of the test structure. Side-on pressure histories were measured at a number of scaled distances out the front (the direction in front of the vent opening), side, back, and out diagonally between the side and back of the test structure. This test data added to the base of existing information on leakage pressures by measuring the leakage pressures through a partial wall opening and measuring the effect of a vent cover on leakage pressures. The effect of relatively heavy vent panels was to significantly reduce the peak pressures (by a factor of 3 approximately) and impulse (by a factor of 1.5 approximately) out the front of the structure relative to the case of no vent covering, and to increase the pressure and impulse out the back and, in some cases out the side of the structure, relative to pressures through an uncovered opening. Evidently some of the shock wave, which would otherwise have been focused out the

front of the structure, was reflected towards the side and back by the vent cover as it was translating out from the structure. These data were used to help construct design curves for calculating leakage pressures around missile test cells.

Finally, a small scaled test program was performed at Los Alamos National Laboratory in 1986 to measure the leakage pressure history on the vent wall of the bay adjacent to a bay with an accidental explosion[4]. The testing was conducted because there was concern that the leakage pressures from a bay with an explosion could blow in the light vent walls on adjacent bays and the wall debris could cause detonation of explosives in the adjacent bays. One-eighth scale tests were conducted in which the light metal wall covering the vent area in the bay with the explosion was not modeled. The pressures and impulses measured on an adjacent bay vent wall in two tests were consistent (within 15%) with those predicted with the design curves in References 1 and 2. An axisymmetric hydrocode analysis, using the SALE computer code, was also used to model the leakage pressures and, on the average over the vent wall area, the calculated peak pressures generally agreed well (within 20%) with the measured values. However the calculated impulses were significantly less than measured values.

3.0   Test Program

During a recent test program conducted at Southwest Research Institute (SwRI), leakage pressures were measured through both covered and uncovered vent areas from explosions occurring within a test structure[5]. The test program was conducted primarily to define building wall breakup under blast loading so that an analytical model for predicting maximum hazardous debris distances from buildings subjected to an internal explosion could be developed. However, during many of the tests the surrounding area was instrumented with pressure transducers and leakage pressures were measured from explosions in a quarter-scale test structure shown in Figure 1. Quarter-scale reinforced concrete and masonry test walls were mounted in the back end of the test structure and the front end was either covered or uncovered depending on whether quasistatic pressures were required on the test wall. Several types of vent covers were mounted on the front of the box, ranging from 3/8-in gypsum panels, simulating a light frangible wall, to rigid steel plates which did not allow any venting. In the later case, the test panels failed catastrophically, so that their strength was of negligible importance, and they are considered to be the vent covers in this analysis of leakage pressures. The internal volume of the test structure is 187.5 ft^3 and the scaled vent area is 0.76.

The locations of the transducers used to measure leakage pressures are shown in Figure 2. Two PCB Piezotronics, Inc. 102A05 pressure transducers, which have a pressure range of 0-100 psi, were located directly in back of the test structure (gages Nos 01 and 02 in Figure 2) at 15 feet and 20 feet from the charge location. These two gages were mounted on a steel channel which was buried flush with the ground surface to prevent fragments from striking the transducers. PCB model 137A12 blast pressure probes, which have a pressure range of 0-50 psi, were located out the front side of the structure (Nos 03 and 04) at 15 foot and 20 foot standoffs and out the side of the structure,

in line with the front and back face of the test structure, at a standoff of 15 feet from the centerline of the structure (Nos 05 and 06). A few of the measurements made at locations out the front side of the structure used Model 137A11 probes which have a pressure range of 0-500 psi. Each PCB 137A12 probe was mounted in a holder at the same height as the charge. The pressure-time data were recorded real time using FM, Wideband II, analog tape recorders and were digitized later. Plots of pressure vs time were generated for each of the gages.

A total of 10 tests were performed where leakage pressure measurements were made. Useable pressure measurements were made at the front, rear and sides of the test structure for all tests with the exception of test Nos 1.8 and 2.1 where only the pressures at the back of the test structure were used. A table summarizing these tests has been developed and is included here as Table 1. The scaled vent panel weight listed in this table is the areal density of the panel divided by the cube root of the charge weight. Spherical C-4 explosive charges were used in the tests. The charge weights given in Table 1 are TNT equivalent weights and the standoff is the distance measured from the center of the charge to the test panel mounted in the back of the test structure.

Table 1. Matrix of Tests Where Leakage Pressures Were Measured

Test No.	Charge Wt. (lb)	Standoff (ft)	Venting Condition	Scaled Vent Panel Wt. $(psf/lb^{1/3})$
1.3	2.5	.75	Open	-
1.4	2.5	.75	Covered	27.6
1.5	1.25 + 1.25 = 2.5	.75	Open	-
1.8	2.5	2.5	Covered	1.10
1.9	2.5	2.5	Covered	27.6
2.1	2.0	.75	Open	-
2.2	2.0	.75	Open	-
2.9	1.0	.75	Open	-
2.10	3.0	4.5	Open	-
2.11	.1875	.75	Covered	10.48
2.16	.1875	4.5	Covered	2.62
3.10	3.0	1.5	Open	-

Since the measurement of leakage pressures was not the major goal of the test series, all the factors which could influence the leakage pressures were not studied systematically and measurements were not controlled as well as they would be in a test program dedicated to the measurement of leakage pressures. In particular, two factors of the test program require some discussion. First, the back side of the test structure was actually a test wall which was typically, but not always, failed by the blast. Therefore, the possibility that some of the blast wave exited through the failed test panel in the back of the test structure and increased the leakage pressure to the rear of the test structure, relative to that which would be measured in a structure with a nonyielding backwall, must be addressed. The high speed film coverage of the test panels showed that the major portion of the panels began failing 15 milliseconds or later after the charge was detonated. This indicates that the shock wave had time to exit the test structure through the vent opening since the measured reflected pressure histories inside the test structure show very little impulse at times greater than 15 milliseconds. Also, the pressure data themselves do not indicate that the failure of the test panel on the back side of the test structure significantly affected the measured leakage pressures. This is true because the back panel failed during some tests, while in other tests it did not fail, but there is no trend within the data based on the response of the back panel.

The other factor that may affect the scatter in the data is the accuracy of the measurement system. Most of the pressures measured out the front and side of the test structure used probes with a full-scale range of 50 psi. The electrical output of these transducers, as calibrated by the manufacturer, is linear within 2% of full-scale, which translates to 1 psi. The transducers used out the back of the test structure have a range of 100 psi. The factory calibrated these transducers from 0 to 10 psi and found the linearity over this range to be within 1%, which translates to 0.1 psi. Thus, the maximum expected scatter in the peak pressures as a result of transducer nonlinearity is in the measured pressures 1 psi out the front and side and 0.1 psi out the back. Since the peak pressures measured out the back of the structure are about one order of magnitude lower than the others, the scatter expected as a result of inaccuracies in the measurement system is the same (10% to 20% of the measured peak values) for all the pressure measurements.

4.0   Measured Leakage Pressures

Figures 3 through 8 show a comparison of the leakage pressures measured in the SwRI test program to those predicted from a fully vented three wall cubicle with a roof and a similar loading density using the method in TM5-1300[2] and Reference 1. The prediction curves used from References 1 and 2 were those from a rectangular structure with a shallow, wide footprint, or plan area, since it was the only structure tested at a loading density comparable to those used in this test series. This means that the predicted values, or solid lines, in Figures 3 through 8 represent data measured outside of a structure with a significantly different geometry than the narrow and long SwRI test structure. Here width refers to the distance between sidewalls and depth refers to the distance from the vent opening of the test structure to the backwall. The figures show peak pressures and scaled impulses measured out the front (at gages 03 and 04 in Figure 2), side (gage 05 nearest the vent area only), and back (gages 01 and 02 in Figure 2) of the test structure. The peak pressure

histories measured at the side gage in Figure 2 furthest from the vent area, which have approximately 50% to 65% of the peak pressures and 60% to 75% of the impulse of the pressure histories measured at the forward side gage, are not shown since there is no known prediction method to compare against. All scaled distances in the figures are measured on a straight line from the geometric center of the test structure to the gage location. The measured pressures from tests with a covered vent area are plotted with separate symbols so that the effect of the vent cover can be observed. Figures 3 through 8 show that, on the average, the measured pressure and impulse out the front for tests through uncovered vent areas match the predicted values well. They also show that the pressures and impulse through uncovered vent areas out the side of the test structure are approximately 25% less than the predicted values and the measured pressure and impulse measured out the back of the structure are significantly lower (approximately 70% less) than the predicted values.

The previously mentioned difference in the shape of the test structure from that used for the predicted values is thought to be the primary cause for the difference in the measured and predicted leakage pressures out the side and back of the test structure. It was noted in Reference 1 that structure geometry affected the measured leakage pressure and impulse measured out the back and side of the test structures in that test series. Lower impulses were measured out the back (approximately 30% lower) and out the side (approximately 15% lower) of a cubic structure at scaled standoffs between 10 ft/lb$^{1/3}$ and 20 ft/lb$^{1/3}$ as compared to those measured outside the wide, shallow test structure (width to depth ratio = 5:3) in comparable tests. Measured pressure and impulse out the front of these two structures from comparable tests were almost equal. Since the data measured out the side and back in this test series are also lower than those measured out the back of the wide, shallow structure in Reference 1, and the structure in this test program is much narrower and deeper (with a width to depth ratio of nearly 3:5) than the cubic structure in Reference 1, the differences between predicted and measured pressure and impulse in Figures 5 through 8 confirm the effect of structure geometry noted in Reference 1.

The reduction in leakage pressure and impulse measured out the back and side caused by the cubic shape in Reference 1 and long, narrow shape of the structure in this test series, as compared to the wide, shallow structure in Reference 1, can be characterized by a reduction factor. The fact that the reduction factor is greater for the data in this test series, where the structure was longer and narrower (the reduction factor is approximately 25% out the side and 67% out the back), than for the cubic test structure in Reference 1 (where the reduction factor is approximately 15% out the side and 30% out the back), indicates that the more the shape of the structure focuses the leakage pressure wave out the front, the lower the leakage pressures will be to the side and back. However, structural geometry does not seem to affect the leakage pressure and impulse out the front.

The other major difference between the tests conducted in Reference 1 and the tests in this test series is the charge location within the structure. In Reference 1 the charge was always located at the geometric center of the structure while the charge in this test series[5] was typically, although not always, located deep within the structure in this test series (see Table 1). It does not seem that this difference affected the measured pressure and impulse because the data from the few tests

where the charge was located near the vent opening fit the same trend as the rest of the data measured from charge locations near the backwall. A possible explanation for what seems to be a small effect of charge location is based on an understanding of the leakage blast waves that propagate from the structure. At the scaled distances where pressures were measured in the SwRI test series, the leakage blast wave consists of the incident wave, which propagates directly out the open end of the test structure, and reflections off the floor, roof, backwall and sidewalls of the test structure which also propagate out the open end of the structure and merge with the incident wave. Many of these reflections, and particularly that off the backwall, travel a shorter distance within the structure when the charge is located near the backwall than when it is located nearer to the vent opening. Therefore, the "average" standoff of the numerous reflections which, along with the incident wave, make up the wavefront of the blast wave outside the structure, is near the center of the test structure regardless of the charge location.

Figures 3 through 8 also show the effect of a vent cover on the measured leakage pressures. The figures show that the presence of a vent cover significantly reduces the measured leakage peak pressure and impulse out the front of the test structure and the peak pressure out the side of the structure compared to that measured with no vent cover. The reduction in impulse is slight out the side of the structure and there is no reduction in pressure or impulse out the back of the test structure. The reduction in pressure and impulse caused by the vent cover can be compared with those reported in Reference 3 from a partially vented structure (scaled vent area equal to 0.34 compared to the scaled vent area of 0.76 in the SwRI test series). For similar loading densities and scaled standoffs as those used in the SwRI test series, the peak pressure measured out the front of the test structure in Reference 3 was reduced by approximately a factor of factor of 3.5 and the impulse was reduced by approximately a factor of 2.5 by the presence of a vent panel. As Figures 3 and 4 show, the presence of the vent covers caused a comparable reduction in peak pressure and impulse out the front of the test structure in the SwRI test series. A direct comparison of leakage pressures measured through covered vent areas is not possible because of the difference in scaled vent areas used in these two test series.

The measured effect of the vent cover on leakage pressures out the side and back is somewhat different in the SwRI test series than that measured in Reference 3 at similar loading densities and scaled standoffs. The peak pressures and scaled impulses measured out the side of the test structure in Reference 3 were not significantly reduced by the presence of a vent cover. However, in the SwRI test series the reduction in peak pressure is approximately a factor of 2. The measured reduction in the scaled impulse is negligible and thus, in this respect, the two test series show similar results. Also, in Reference 3, it was found that pressure and impulse were typically increased out the back by the presence of a vent covering. The scatter in the pressures measured out the back in the SwRI test series is such that it can only be stated that the vent cover did not seem to cause any significant increase or reduction in the measured leakage pressures. On the average, the leakage peak pressure and impulse measured out the back through covered vent openings are largely equal to those measured through uncovered vent openings.

In summary, the comparison of leakage pressures measured out the front of the test structure in the SwRI test series to those measured in Reference 3 indicate that the effect of a vent cover on leakage pressures out the front is not influenced by scaled vent areas between 0.34 and 0.76. The comparison of leakage pressures measured out the back and side of the SwRI test structure to those measured in Reference 3 indicates that the effect of a vent cover on leakage pressures in these directions is influenced by the scaled vent area. The fact that the presence of a vent panel caused the leakage pressures to increase out the back and decrease out the open front of the structure in Reference 3 indicates that the vent cover is probably redirecting some of the leaked blast wave towards the rear of the structure as it translates out from the structure. The fact that the same trend occurs in the SwRI test series, which has a much larger scaled vent area, but that it is more moderate in that there is minimal or zero increase in leakage pressures out the back and side, indicates that the leaked blast wave is redirected to a larger extent when it is more focused by a smaller scaled vent opening. This seems to be true at least for the scaled vent areas between 0.34 used in Reference 3 and 0.76 used in this test series.

A final important observation is that the scaled weight of the vent cover does not seem to significantly affect the measured leakage pressures. As Table 1 shows, the test matrix includes a wide assortment of scaled vent cover weights but Figures 3 though 8 show that all the data measured from covered vent areas fit the same general trend. Figure 2-150 in TM5-1300[2] shows that the vent walls used in this test series are capable of reflecting almost all of the initial internal shock wave. Therefore, this may be the reason the scaled vent panel weight had no measurable affect on the leakage pressures in this test series. The reduction in leakage pressure out the front caused by a vent cover may also be largely due to the fact the wave must detract around the vent panel as it translates out from the structure. In this case it also makes sense that the panel weight would not be important. Also, the scaled vent cover weight and scaled recessed distance of the vent panel relative to the outside face of the structure did not seem to cause any consistent or strong effect on the leakage pressures measured through covered vent openings in Reference 3. This helps confirm the similar observation in this test series which is based on much more limited data.

Figures 9 through 11 show a comparison between the measured scaled arrival time of the largest measured leakage pressure pulse at gages in front, to the side, and in back of the vent opening with the scaled arrival time predicted by the TM5-1300[2] airblast curve for a hemispherical surface burst. The scaled distance used in the airburst curve is based on the line of sight distance from the actual charge location to the gage through the vent opening and, for gages in the back and side of the structure, around the structure. These figures show that the time of arrival of the peak pulse through an uncovered vent opening can be predicted relatively well with this method. The figures also show that the vent panels significantly delayed the arrival of the peak pressure pulse. The fact that some of the scaled arrival times at gages out the back of the test structure through covered vent openings were not affected by the vent cover is due to the fact that, for these tests, the peak pulse arrived as an initial pulse in the train of blast pulses measured at this location, rather than as a later pulse as was typical. Therefore, this is an anomaly rather than a significant trend.

Figures 12 through 14 show some examples of measured leakage pressure histories out the front, side, and back of the structure through uncovered vent openings. The measured pressure histories out the front and side through uncovered openings are characterized by a single pulse which contains almost all of the impulse. The pressure history out the back is characterized by two to three pulses with significant pressure and impulse. The pressure histories out the back are better characterized by an isosceles triangle rather than the right triangle typically used to represent blast pressure pulses and their duration is significantly longer than the single pulse pressure histories out the front and side of the structure. The form of the measured pressure histories from uncovered vent openings in this test series are similar to those reported in Reference 1 from three-walled cubicles with a roof at similar scaled standoffs.

Figures 15 through 17 show some examples of measured leakage pressure histories out the front, side, and back of the structure through covered vent openings. The pressure histories measured out the front and side through covered openings are similar in form to those measured out the back through uncovered openings. It is possible that this similarity is due to the fact that the vent cover is an obstruction to the propagation of the leakage blast waves out the front and side of the structure in the same way the structure itself is an obstruction to the leakage blast wave out the back of the structure. The measured pressure histories indicate that such obstructions increase the distance required for the trailing pressure pulses from reflections within the structure to merge with the incident pulse that propagates directly out the vent opening.

5.0   Conclusions

The following conclusions can be drawn from the analysis of the test data presented in this paper and the data from preceding test series discussed in this paper. In general, only trends in the data, rather than quantified relationships, can be concluded because of the limited amount of data that was measured.

1) Structure geometry does not significantly affect the leakage pressure and impulse out the front of fully vented structures with roofs at the scaled distances measured in both this test series and in Reference 1 (scaled distances greater than 10 ft/lb$^{1/3}$).

2) Structure geometry does seem to affect the leakage pressure out the side and back of fully vented structures. Based on data from Reference 1 and from this test series, the greater the width to depth ratio of the structure (depth is the dimension between the vent opening and the backwall-width is the dimension between sidewalls), the larger the leakage pressure and impulse out the side and back of the structure at standoffs measured from the center of the structure.

3) Charge location within the structure does not seem to affect the measured leakage pressures.

4) The presence of a panel over the vent wall (with a scaled vent area of 0.76) significantly decreased the peak leakage pressure (by a factor near 3.5) and positive phase impulse (by a factor near 2.5) out the front of the test structure. A vent panel decreased the peak leakage pressure out the side (by a factor near 2) of the structure but did not significantly decrease the impulse. The average measured leakage pressure and impulse out the back of the structure was not affected by the presence of a vent panel.

5) The effect of the vent cover on leakage pressures stated in number 4 is only consistent with the effect measured out the front of the covered vent openings in comparable tests in Reference 3, where the scaled vent area was only 0.34. This indicates that the effect of a vent panel on leakage pressures out the side and back of the structure is dependent on the scaled vent area.

6) The scaled weight (areal density divided by the cube root of the charge weight) of the vent panel does not seem to affect the leakage pressures outside the test structure, particularly those measured out the front and side. Because of the scatter in the data out the back, no definite conclusion can be drawn for this case.

7) The scaled arrival time of the main pulse of the measured leakage pressure histories through uncovered vent areas could be predicted well using the scaled line of sight distance from the charge to the point of interest and the airblast curves for a hemispherical ground burst in TM5-1300[2].

6.0   References

1. Keenan, W.A. and Tancreto, J.E., "Blast Environment From Fully and Partially Vented Explosions in Cubicles," Report No. TR-828, Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, CA, November 1975.

2. Design Manual Army TM5-1300, NAVFAC P-397, and AFM-88-22: Structures to Resist the Effects of Accidental Explosions, Department of the Army, Navy, and Air Force, Washington, DC, 1990.

3. Tancreto, J., Missile Test Cell Design Load and Safe Siting Criteria, Technical Memorandum, No. 51-86-15, Naval Civil Engineering Laboratory, Port Hueneme, CA, August 1986.

4. Smith, P.D. and Crawford, T.R., "Effects of Explosion on Adjacent Bay Blowout Walls," from Minutes of the 22nd Explosive Safety Seminar, August 26-28, 1986, Anaheim, CA, pp. 105-118.

5.   Bowles, P.M., Oswald, C.J., Vargas, L.M. and Baker, W.E., "Debris Hazard Evaluation, Task 3: Test Program and Predictive Model Refinement," Draft Final Report, prepared for Bernard Johnson, Inc., under Mason & Hanger Silas Mason, Inc., Contract H0760103, U.S. Government Contract DE-AC04-76DP-00487.
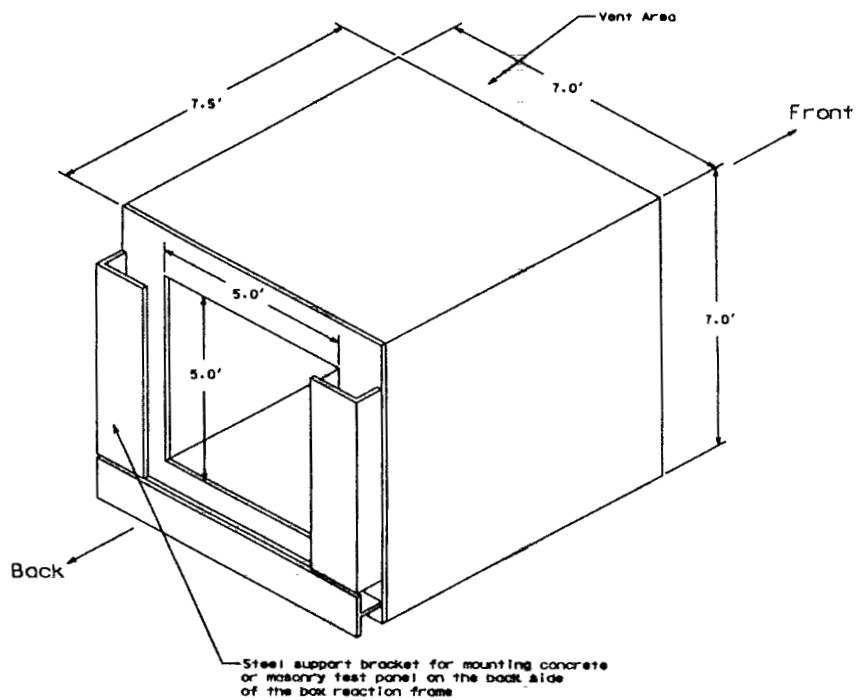
Figure 1. Test Structure Showing Mounting Bracket for Test Panel on Back Side and Vent Area on Front Side
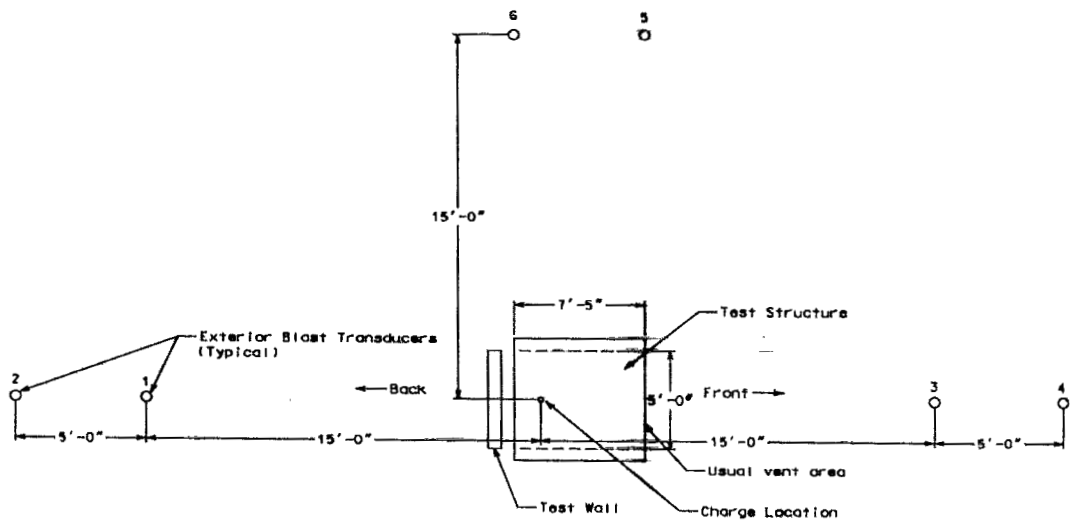

Figure 2. Plan View Showing Locations of Blast Pressure Transducers (Nos. 01 through 06) Used to Measure Leakage Pressures from Test Structure
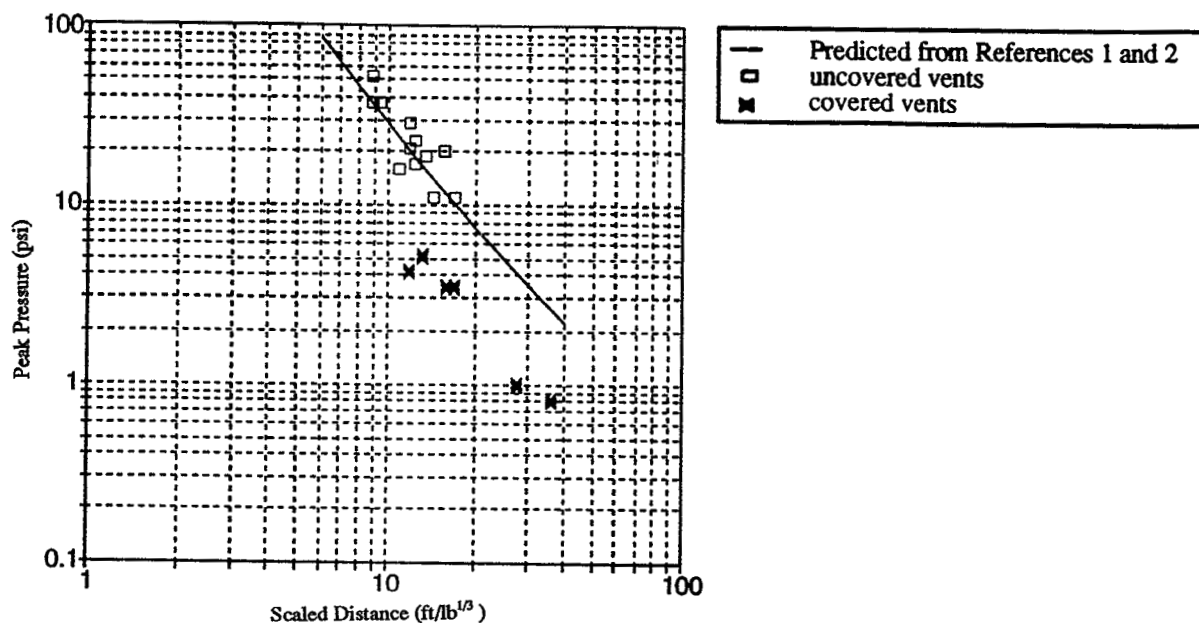
Figure 3. Peak Leakage Pressures Measured Out the Front of Test Structure Compared to Predicted Values in References 1 and 2
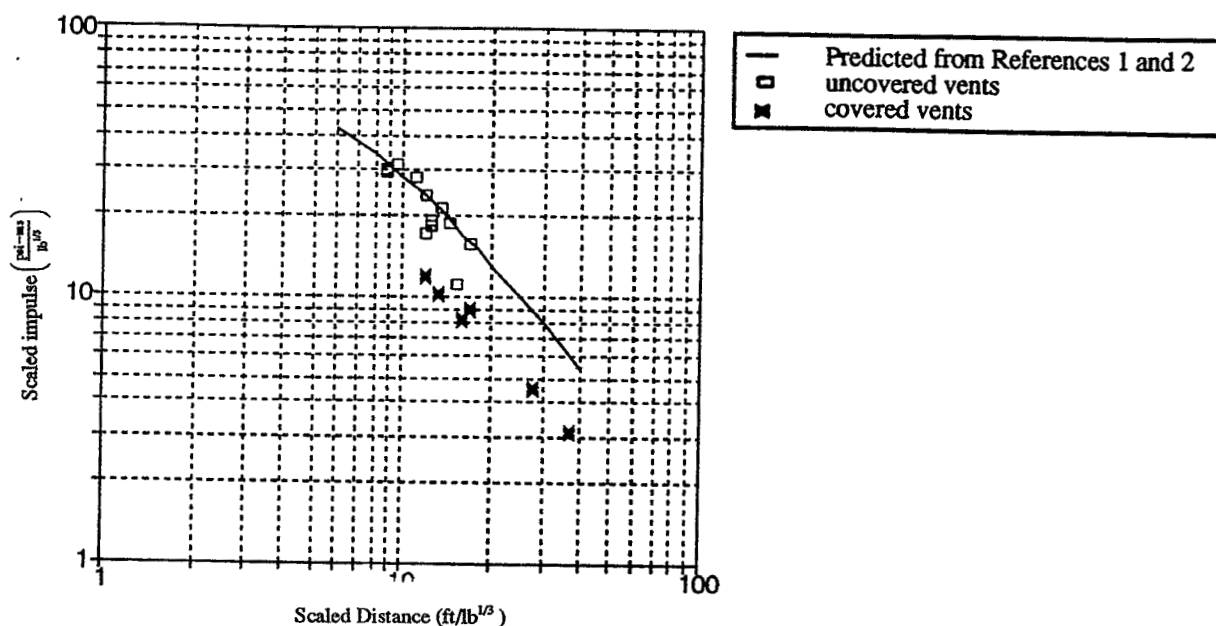
Figure 4. Scaled Leakage Impulse Measured Out the Front of Test Structure Compared to Predicted Values from References 1 and 2
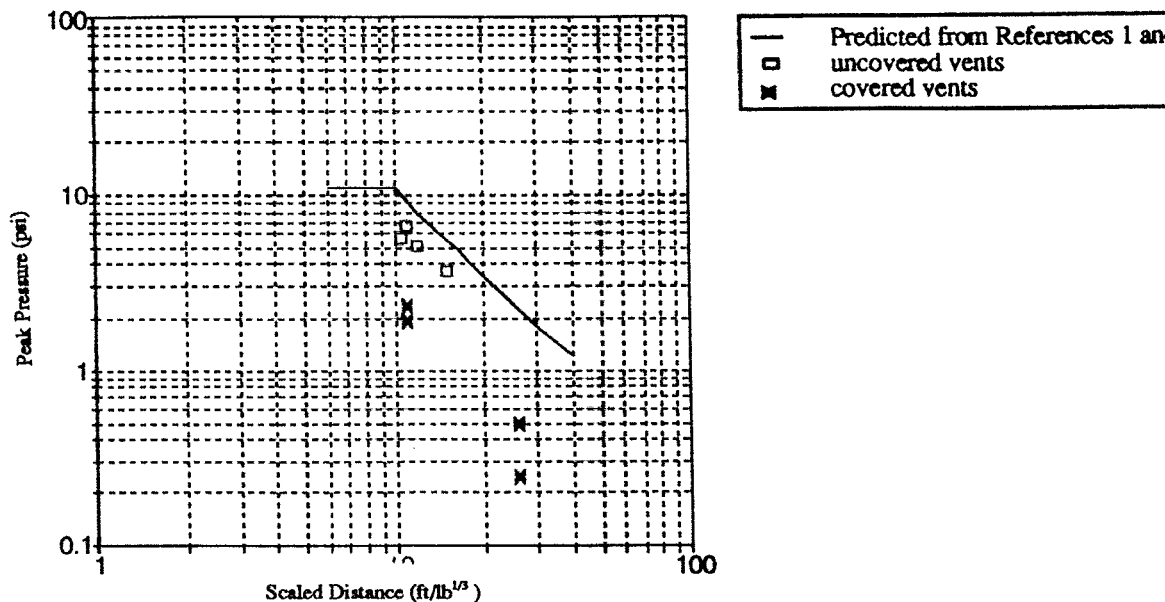
Figure 5. Peak Leakage Pressure Measured Out the Side of Test Structure Compared to Predicted Values in References 1 and 2
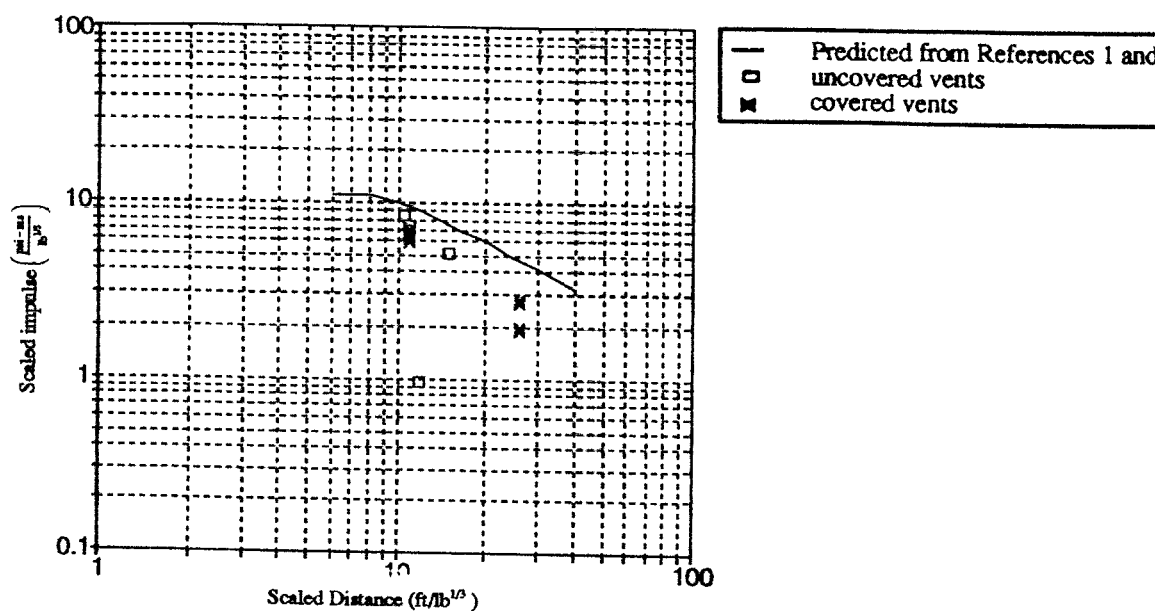
Figure 6. Scaled Leakage Impulse Measured Out the Side of Test Structure Compared to Predicted Values in References 1 and 2
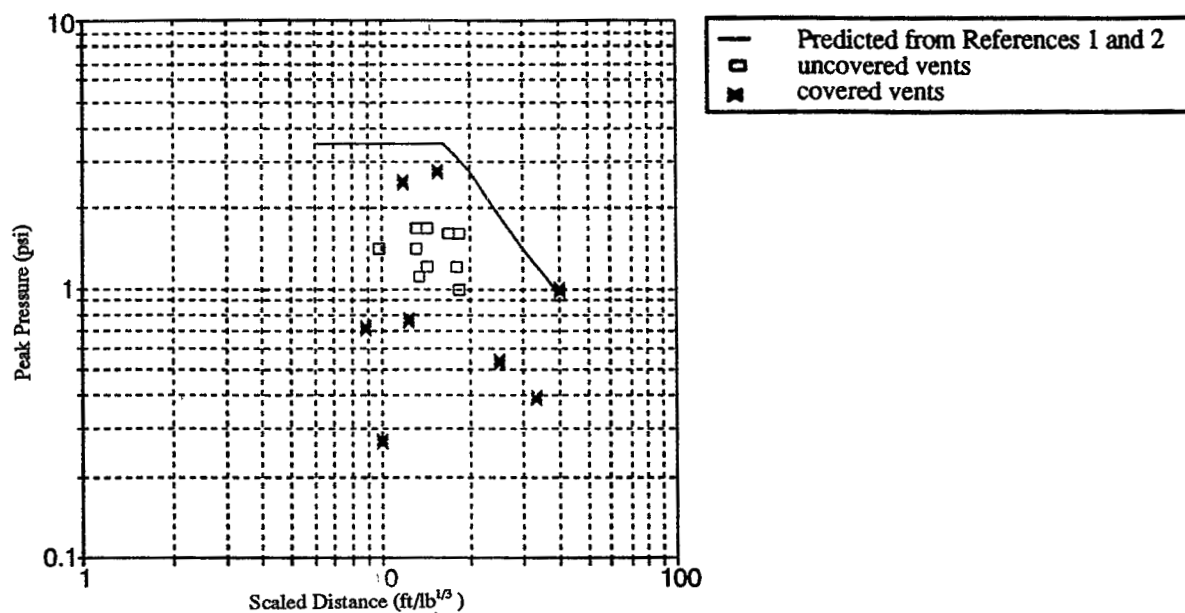
Figure 7. Peak Leakage Pressures Measured Out the Back of Test Structure Compared to Predicted Values in References 1 and 2
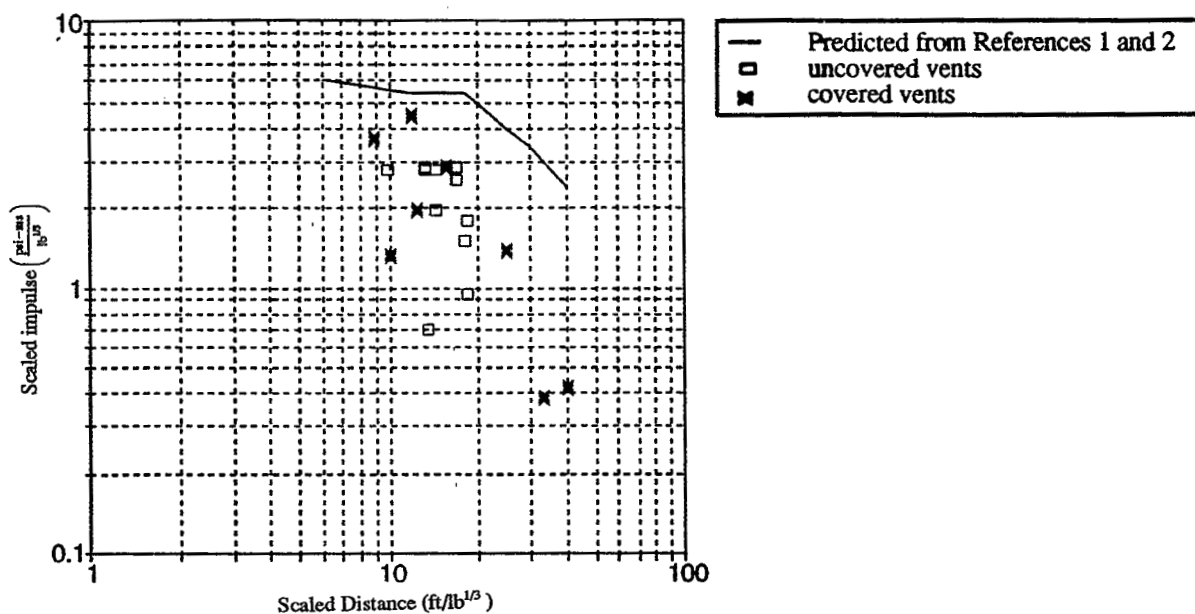
Figure 8. Scaled Leakage Impulse Measured Out the Back of Test Structure Compared to Predicted Values in References 1 and 2
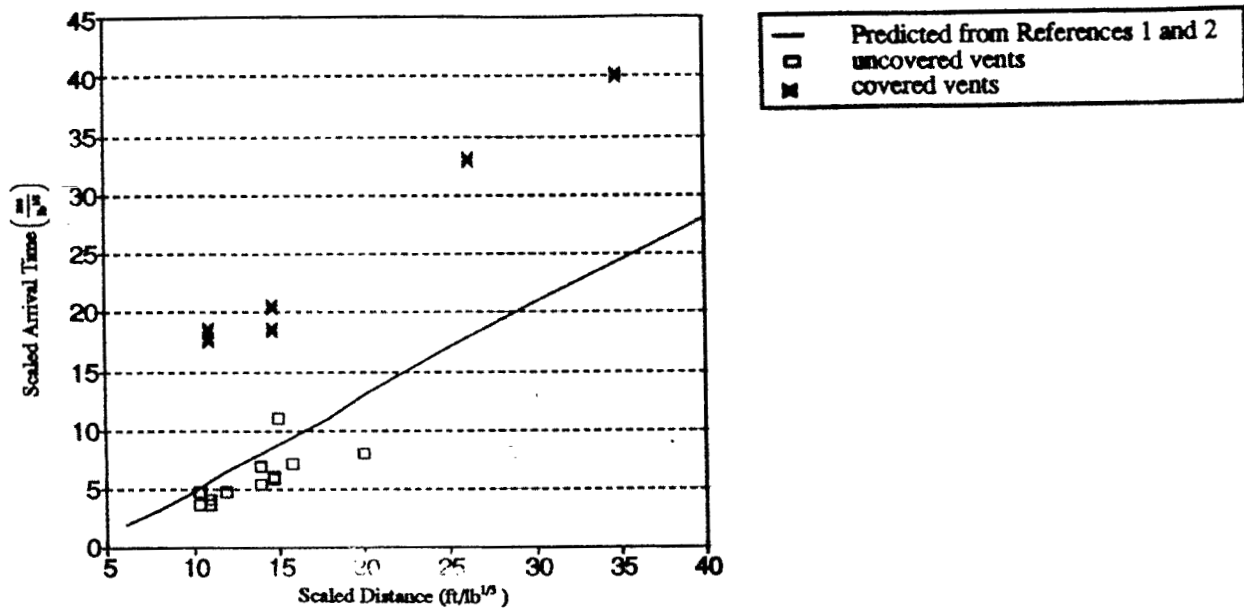
Figure 9. Scaled Arrival Time of Peak Leakage Pressure at Scaled Distances Out the Front of Test Structure
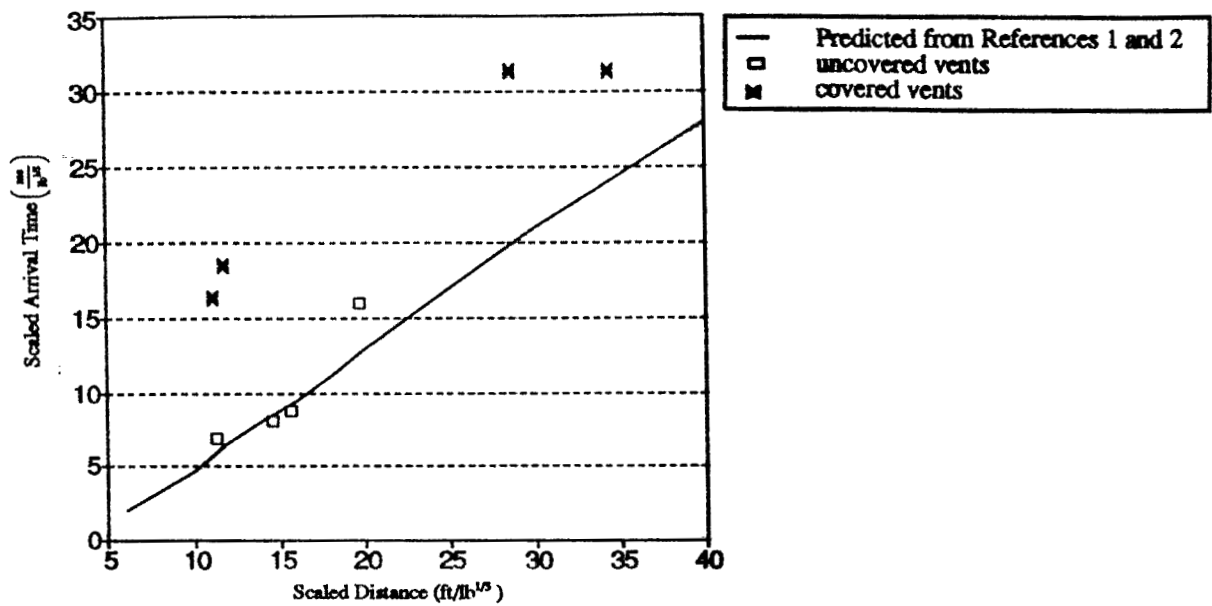
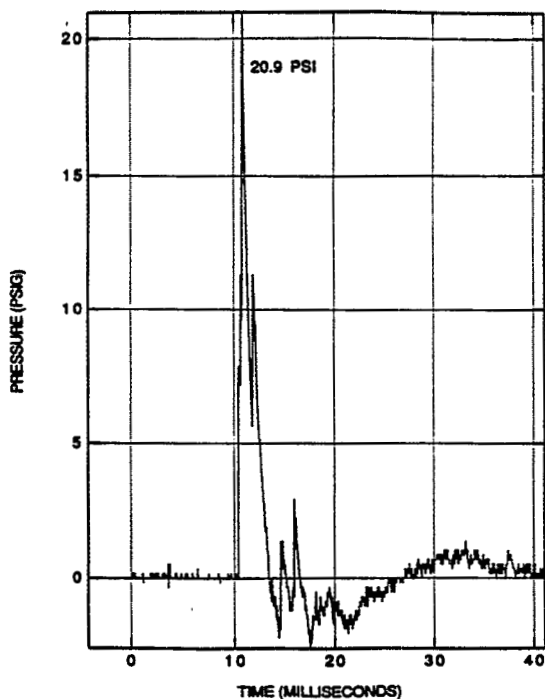**Figure 10. Scaled Arrival Time of Peak Leakage Pressure at Scaled Distances Out the Side of Test Structure**
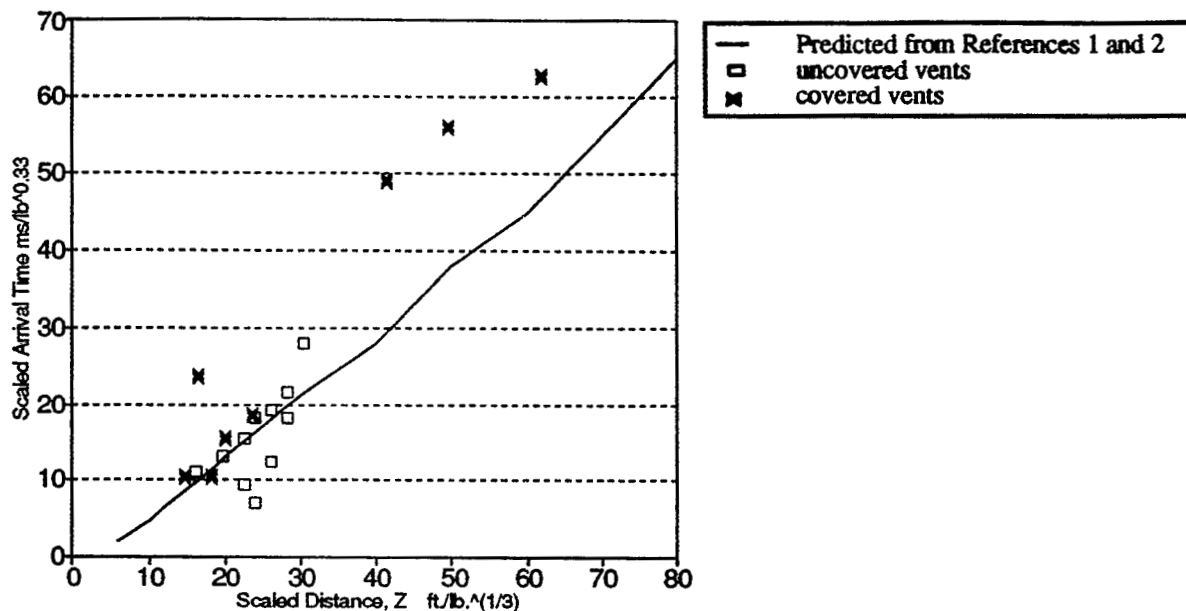
Figure 11. Scaled Arrival Time of Peak Leakage Pressure at Scaled Distances Out the Back of Test Structure

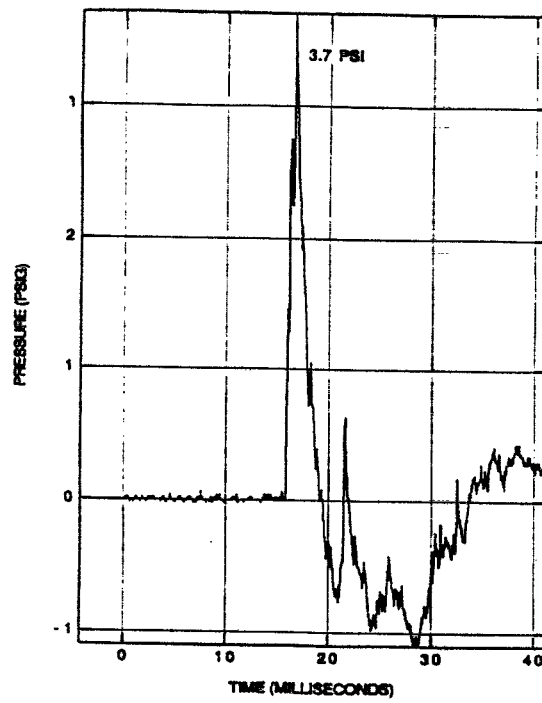**Figure 12. Typical Leakage Pressure History Measured Out the Front of Test Structure Through Uncovered Vent Opening**

Figure 13. Typical Leakage Pressure History Measured Out the Side of Test Structure Through Uncovered Vent Opening
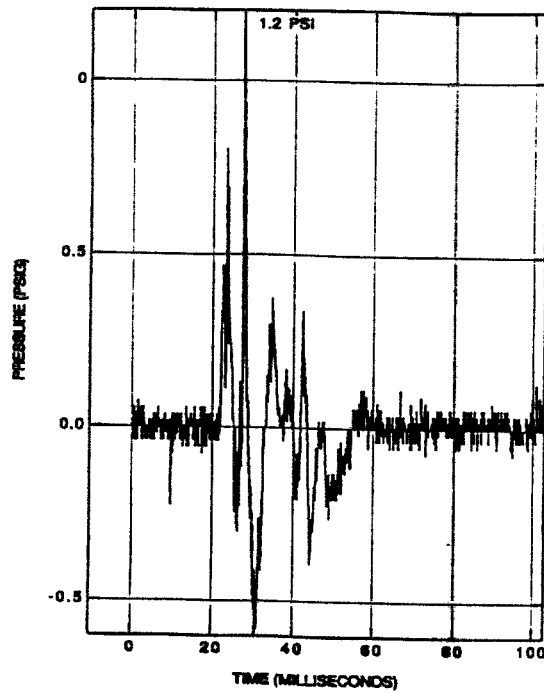

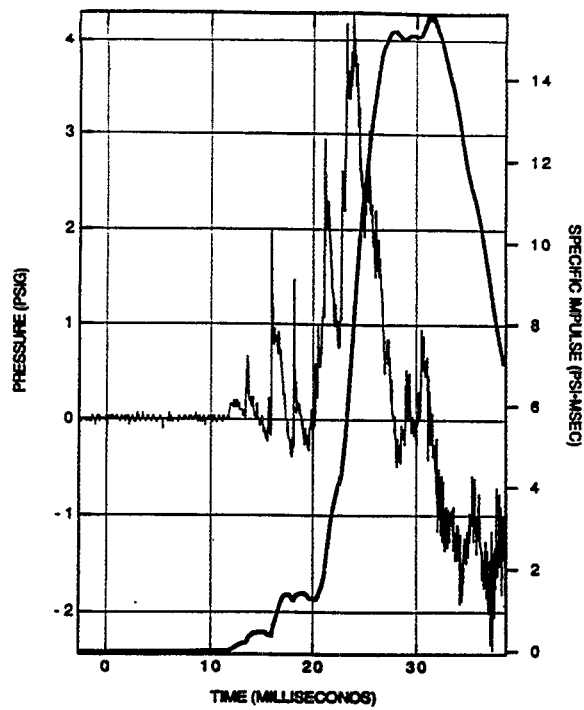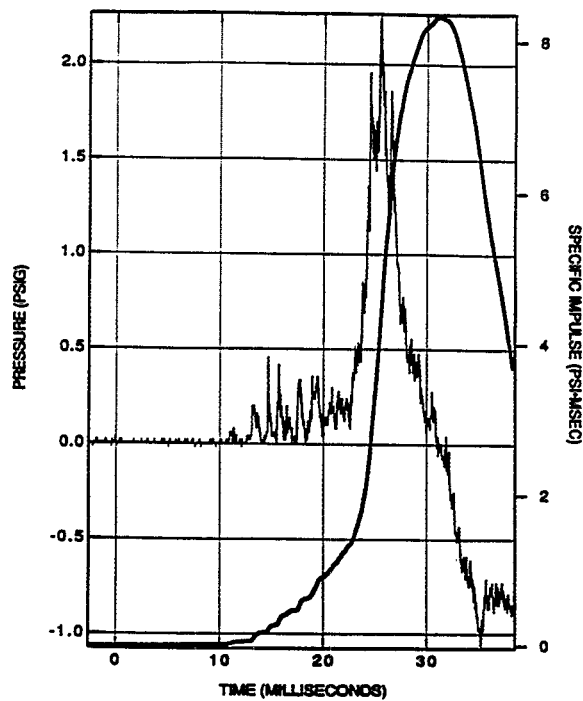**Figure 14. Typical Leakage Pressure Measured Out the Back of Test Structure Through Uncovered Vent Opening**

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Figure 15. Typical Leakage Pressure History Measured Out the Front of Test Structure Through Covered Vent Opening

Figure 16. Typical Leakage Pressure History Measured Out the Side of Test Structure Through Covered Vent Opening
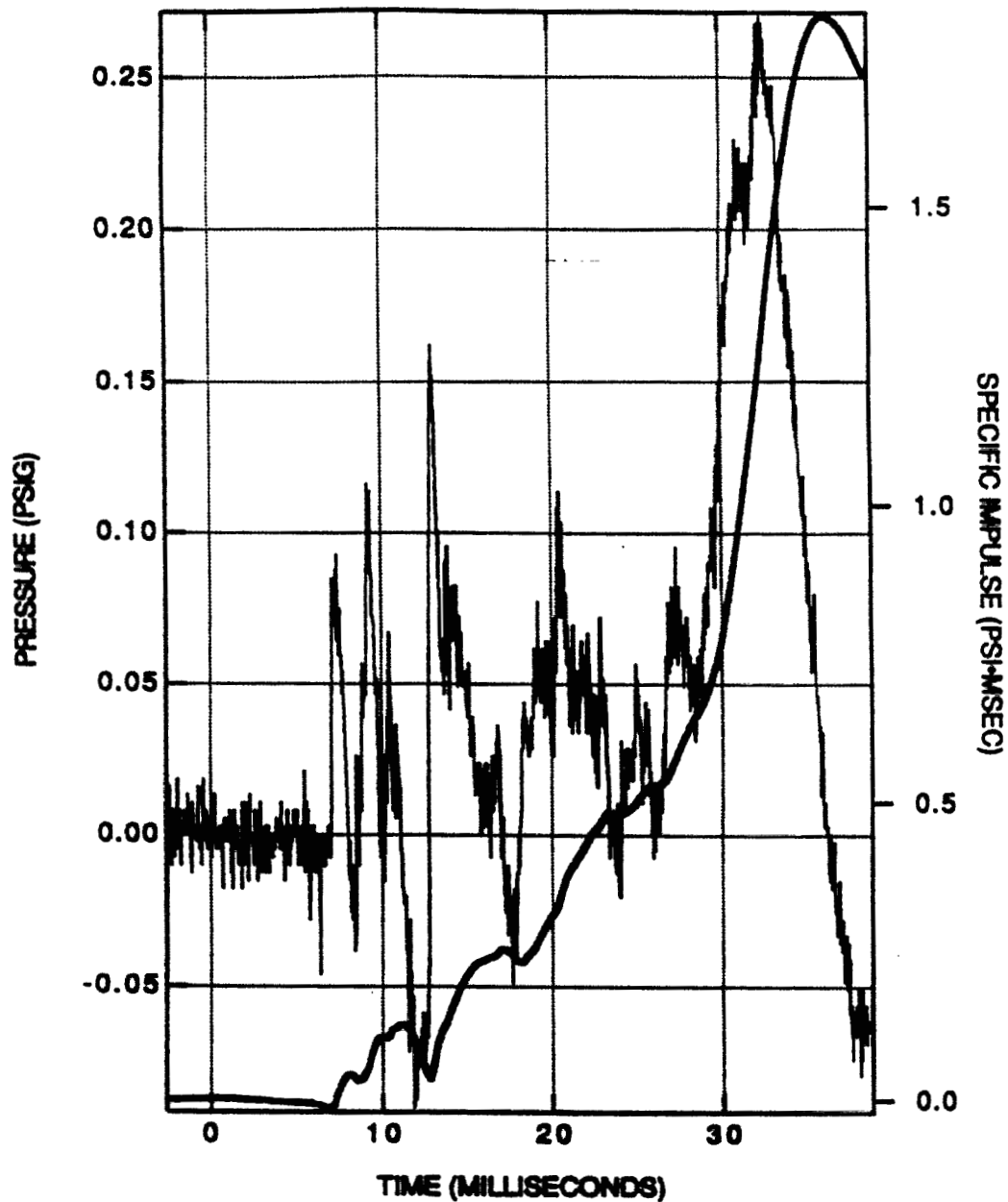
Figure 17. Typical Leakage Pressure History Measured Out the Back of Test Structure
Through Covered Vent Opening